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Lime Stabilized Biosolids, Pelletized Broiler Litter, and Inorganic Fertilizer Applications in a 1986 planted, unthinned Longleaf Pine Stand

Ten Year Report on the Sand Hills State Forest, South Carolina

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SECTIONS:

I. PROJECT BACKGROUND

This project was initiated on the Sand Hills State Forest in Chesterfield County, South Carolina (SC) in the spring of 1995 to determine the effects/benefits of inorganic fertilizer, the Town of Cheraw lime stabilized biosolids, and pelletized broiler litter applications in a 9-year old planted, unthinned longleaf pine stand. Major objectives included quantifying the magnitude and duration of (1) pine straw (litter layer dry weight) response, (2) tree/stand growth (dbh, basal area/acre, height, volume /tree and volume/acre) response, and (3) topsoil (0-6") pH changes in the biosolids plot over the four year initial funding period. The experimental design was a randomized complete block with two replications in a 1986 planted (8x9 feet spacing with 425-525 trees per acre at time of treatment) longleaf pine stand. The soil series was verified by a Natural Resources Conservation Service (NRCS) soil mapper as the Alpin soil series, which is an excessively drained, deep sand (Lamellic Quartzipsamments). Gross treatment plots (145 x 145 feet) were installed within the soil delineated stand. Permanent measurement plots (104.5 x 104.5 feet) were installed within each treated plot. Forty feet of untreated buffer separated each plot. Forest floor and surface soil samples were collected prior to fertilizer and biosolids treatments. Since spring growth had already initiated, foliage samples were not taken prior to plot treatments. All living longleaf trees in each permanent measurement plot were aluminum tagged @ 4.5 feet above groundline; diameter at breast height (dbh), numbered, and measured for dbh and total height prior to treatment application. Plots were randomly assigned a treatment.

Fertilized plots were first treated in May - June 1995. Treatments were as follows: control (no fertilizer), 10-10-10 @ 1500 lbs/ac (150 lbs/ac nitrogen, 65 lbs/ac elemental-phosphorus, and 125 lbs/ac potassium; NPK), lime stabilized biosolids (biosolids @ 8 wet tons/ac; 40% solids, 4.5 wet tons = 1 ton agricultural lime, 210 lbs total-N, 80 lbs plant available-N, 110 lbs P2O5, 11 lbs K2O, ,900 lbs Ca, 6.4 lbs Mg/acre, Table 1). The lime stabilized biosolids were applied with a tractor pulling a PTO driven Knight side port manure spreader. The NPK fertilizer was applied by tractor with a PTO driven cyclone spreader. Pelletized broiler litter was not applied in 1995. Forest floor, soil, and foliage samples were taken each January-February thereafter. All living tagged trees were re-measured (dbh, total height) in February-March 1997, 1999, July 2001, March 2003 and August 2005.

Plots were treated a second time on 21 May and 22 June, 1999. The treatments were: control=no treatment, 10-10-10 @ 850 lbs/ac (NPK treatment), and pelletized broiler litter (3.4% N, 2.7% P2O5, and 1.3% K_2O to replace the biosolids treatment which were not applied a second time) @ 3,750 lbs/ac. The NPK fertilizer and pelletized broiler litter were applied with the same tractor and cyclone spreader as was used in 1995.

II. LONGLEAF PINE FOREST FLOOR NUTRIENT CONCENTRATIONS AND WEIGHT/ACRE ESTIMATES

Estimation of forest floor nutrient concentrations and weights per acre in longleaf pine stands can be of great importance when pine straw (litter layer) is removed (raked) from the site. In many cases, the fermentation and humus layers after pine straw harvesting can be displaced, partially removed, decomposition rates of these layers may increase, and/or these layers may be unevenly distributed in the stand. Knowledge of forest floor nutrient concentrations and weight per acre estimations can also be useful on these inherently infertile and droughty deep sands of the Sand Hills physiographic region. Estimating the impact of fertilization on nutrient concentrations and amounts in the litter and fermentation plus humus layers can be important for planning intensive harvesting regimes. Six one square foot grids of forest floor samples were taken per plot prior to a one-time lime stabilized biosolids and inorganic fertilizer application in May-June 1995 and then each January-February after fertilizer application through February 2000. These forest floor samples were separated into litter layer (fresh brown needles representing straw that would be harvested) and fermentation plus humus layers. All samples were paper bagged, labeled, oven dried at 158 degrees F for 48 hours and dry weighed. The dry weight was converted to pounds per acre dry weight for each plot. A subsample from each forest floor sample was analyzed for N, P, K, Ca, and Mg concentrations. These forest floor concentrations were multiplied by the number of pounds per acre for each plot in each year to estimate a weight per acre of each nutrient in each layer over time by treatment. A comparison of pre-application (May 1995) and 3 years post-application when forest floor dry weights were peaking for the fertilized treatments are summarized as follows.

FOREST FLOOR LITTER (L) AND FERMENTATION+HUMUS (FH) LAYER NITROGEN (N)

Pre-application (May 1995) forest floor litter layer N concentrations for all treatments were 0.33% (Table 1). Post-application 1998 litter layer N concentrations ranged from 0.29 to 0.35%. Fermentation plus humus layers (FH) N concentrations ranged from 0.67 to 0.95% pre-application in 1995 and ranged from 0.32 to 0.47% in 1998 three years post-application (Table 1) Pre-application litter layer N estimated weights ranged from 5.6 (control) to 8.0 lbs/ac (biosolids). Three years post application (1998) N litter layer weights ranged from 7.5 (control) to 17 lbs/ac (biosolids; Table 2).

FOREST FLOOR LAND FH LAYER PHOSPHORUS (P)

Pre-application L and FH layer P concentrations ranged from 0.035 to 0.045% and 0.03 to 0.04%, respectively (Table 1). Three year post application (1998) L and FH layer P concentrations ranged from 0.035 to 0.045% and 0.03 to 0.04%, respectively (Table 1). Pre-application forest floor L layer P weight ranged from 0.69 to 0.73 lbs/ac(Table 2). Three year (1998) post application L layer P weights ranged from 1.1 (control) to 1.7 lbs/ac (NPK and biosolids; Table 2).

FOREST FLOOR L AND FH LAYER POTASSIUM (K)

Pre-application L and FH layer K concentrations ranged from 0.035 to 0.055% and 0.02 to 0.03%, respectively (Table 1). Three year post application (1998) L and FH layer K concentrations ranged from 0.03 to 0.06% and 0.03 to 0.04%, respectively (Table 1). Pre-application forest floor L layer K weights ranged from 0.75 to 0.82 lbs/ac (Table 2). Three year (1998) post application L layer K weights ranged from 0.87 (control) to 2.9 lbs/ac (NPK; Table 2).

FOREST FLOOR LAND FH LAYER CALCIUM (CA)

Pre-application L and FH layer Ca concentrations ranged from 0.37 to 0.62% and 0.25 to 0.43%, respectively (Table 1). Three year post application (1998) L and FH layer P concentrations ranged from 0.43 to 0.52% and 0.45 to 0.51%, respectively (Table 1). Pre-application forest floor L layer Ca weights ranged from 8.5 to 11.0 lbs/ac (Table 2). Three year post application (1998) forest floor L layer Ca weights ranged from 11 (control) to 25 lbs/ac (biosolids; Table 2).

FOREST FLOOR L AND FH LAYER MAGNESIUM (MG)

Pre-application L and FH layer Mg concentrations ranged from 0.035 to 0.055% and 0.015 to 0.02%, respectively (Table 1). Three year post application (1998) L and FH layer Mg concentrations was 0.045 for all treatments and 0.035 to 0.045%, respectively (Table 1). Pre-application forest floor L layer Mg weights ranged from 0.75 (control) to 1.0 lbs/ac (NPK; Table 2). Three year post application (1998) forest floor L layer Mg weights ranged from 1.1 (control) to 2.2 lbs/ac (NPK and biosolids; Table 2).

PINE STRAW PRODUCTION ESTIMATES

Pine straw production rates were estimated from six one square foot grids randomly located in each plot starting in February 1996 through February 1999. The February 2000 collection amounted to 14 bales/ac for the control, 28 bales/ac for the NPK, and 24 bales/ac for the biosolids then pelletized broiler litter (applied in 1999) treatments due to the stand having been raked prior to collection. Thus, the litter layer weights could no longer be estimated after the 1999 collection. There was no significant pine straw (litter layer) gain with NPK or biosolids fertilization nine months post initial application (Figure 1). This is to be expected as pine needles tend to stay on the tree for an average of 18 months (range of 1 to 2 years). In the second year post-NPK and biosolids application, there was a significant pine straw gain over the control of 34 and 61 bales/acre, respectively (Figure 1). The plots that were fertilized with NPK (193 bales/ac) or lime stabilized biosolids (197 bales/ac) had greater pine straw values than the control in the third year (1998) after initial application (Figure 1). The control treatment produced 391bales/acre, the NPK treatment produced 504 bales/acre, and the biosolids treatment produced 554 bales/acre from February 1996 through February 1999. The NPK treatment produced 113 extra bales/acre and the biosolids treatment produced an extra 163 bales/acre over the control during this period. This equates to an extra $56 to $81/acre in pine straw revenues (@ $0.50/bale using 1995-2000 South Carolina values) and $112 and $162/acre more revenue during 2015-2020 at $1/bale values for the NPK and biosolids treatments, respectively from 1996 through 1999.

III. SOIL PH AND LB/AC NUTRIENT ESTIMATES

Topsoil (0-6") pH changes in the lime stabilized biosolids plots (as well as all other plots) were monitored closely prior to treatment applications in May-June 1995 and the first 32 months after application (Dickens 1998). In a companion study on the Sand Hills State Forest, the 1963 planted, thinned twice longleaf stand surface soil pH had risen from 4.6 in 1995 prior to the first lime stabilized biosolids application to 5.2 in 1999 prior to the second applications and from 5.2 in 1999 to 6.2 in 2002 after the second lime stabilized biosolids application (@ 12 wet tons/ac) (Dickens and others 2020).

FEBRUARY 1996 – MARCH 1999 FIRST APPLICATION PERIOD

Unlike the 1963 planted stand (Dickens and others 2020), the 1986 planted stand had higher pre-application topsoil (0-6") phosphorus (P) levels, ranging from 20 to 57 lbs of available-P per acre in 1995 (Table 3). Topsoil extractable-P decreased for all treatments during the first application period (1995 through spring 1999) by 8 to 39 lbs/ac (Table 3), but was above sufficiency for all the treatment means for the ten year study period (Table 3). Soil available-P (approximated by soil extractable-P) in the NPK (44 lbs/ac) plots peaked 2-years after the first application. Soil extractable P concentrations of less than 6-10 lbs/acre (using Mehlich I extract procedure at UGA and Clemson University, Kissel and Sonon 2008, Clemson University Ag. Service Lab 2020) are considered to be below minimum guidelines for loblolly, longleaf, and slash pine (Dickens and others 2016).

There are currently no established soil N, K, Ca, or Mg minimum guidelines for loblolly, longleaf or slash pine (using Mehlich I extraction procedure). Nonetheless, trends over time from this project illustrate that both the inorganic and organic fertilizers did not persist for more than 4 years (except calcium from the biosolids) in the surface soil on these deep, excessively drained sands after the first application. Forest floor weights (lbs/acre or bales/acre), soil available-P, and foliar N concentration (Table 4) were good indicators of the short nutrient persistence period in the soil gained from the fertilizers on these deep sands. Generally, the fertilizer response was greatest in the third year for forest litter layer dry weights (Figure 1).

MARCH 1999 –AUGUST 2005 SECOND APPLICATION PERIOD

Surface soil available-P continued to stay above the minimum guidelines during the second application period for all treatments (Table 3). Soil available-P increased from 24 lbs/ac in 1999 to 67 lbs/ac in 2000, 99 lbs/ac in 2002, but declined to 54 lbs/ac in 2005 in the NPK treatment (Table 3). The 54 lbs/ac of available-P in the NPK plots six years after the second application, may illustrate that P may persist at least six years in the surface soil on these deep sands. Soil available-K followed a similar pattern as available-P, as K increased with the second application from 17 lbs/ac in 1999 to 25 lbs/ac in 2000 and 2002, but dropped to 15 lbs/ac during 2005 in the NPK plots.

IV. FOLIAR NUTRIENT CONCENTRATIONS

Foliage samples were not collected prior to inorganic and organic fertilization due to the project's initiation timing (after the initiation of growth in the spring of 1995). Foliage samples were taken in Jan-Feb of 1996, 1997, 1998, 1999, 2000, 2001, 2002, and 2003.

FEBRUARY 1996 – MARCH 1999 FIRST APPLICATION PERIOD

Mean foliar N levels were above the 0.90% sufficiency level for longleaf pine for the control treatment in 1996 but fell below sufficiency in 1997 and 1999 (Table 4). The NPK treatment mean foliar N levels were below sufficiency from 1996 through 1999. The biosolids treatment mean foliar N values were above the minimum guideline in 1996 and 1997 but fell below sufficiency in 1999. Mean foliar P levels for all treatments and assessment timings were at or above the sufficiency level. Mean foliar K was at or above sufficiency for all treatments in 1996 and 1997, falling to at or below sufficiency in 1999 in the biosolids treatment (Table 4). Mean foliar Ca was above the minimum guideline level for longleaf pine for all treatments. Mean foliar Mg was slightly above sufficiency in the control treatment in 1996 but at sufficiency in 1997 and 1999 (Table 4). Foliar Mg for the NPK treatment was at or below sufficiency in 1996, 1997 and 1999. Foliar Mg in the biosolids treatment was below sufficiency in 1996 but was above sufficiency in 1997 (Table 4).

MARCH 1999 –AUGUST 2005 SECOND APPLICATION PERIOD

Mean foliar N and P levels were above the sufficiency level for all treatments during the second application period (Table 4). Foliar K levels were below sufficiency in the unfertilized (control) treatment in 2000 and 2001, but were above sufficiency in 2002 and 2003 (Table 4). Foliar K was above sufficiency in the NPK and pelletized broiler litter (PBL) treatments during the second application study period. Foliar Mg was above sufficiency in 2000 for all treatments (Table 4). Foliar Mg was at sufficiency for the control and NPK treatments in 2001 and below sufficiency for the NPK treatment in 2002 (Table 4). Foliar Mg for the PBL treatment was above sufficiency during the second application study period.

V. TEN YEAR LONGLEAF PINE TREE/STAND GROWTH AND SURVIVAL

There were no statistically significant growth parameter differences among treatments during the ten-year study period (Tables 5a, 5b, 6a, and 6b). This may be due to (1) the sufficient soil available-P levels prior to treatment application and during the study period, (2) surface soil total-N levels in the control treatment being 3-fold greater in the 1986 stand than in a similar 1963 planted stand (Dickens and others 2020), (3) foliar P levels were at or above sufficiency in the control treatment during the study period, (4) and foliar N, P, and K levels from the control treatment did not show a deficiency in 1996.

There was an increase in the four-year dbh growth increment to both the NPK (10-10-10 @ 1,500 lbs/ac) and the biosolids application when compared to the control dbh incremental growth (Table 5a). The first four years (1995-99) dbh incremental gain in the NPK and biosolids fertilized treatments versus the control were 0.40 (29% gain) and 0.20 inches (14% gain), respectively (Table 5a and 7). The second six years (1999-2005) dbh incremental gain for the NPK and pelletized broiler litter treatments were 0.40 and 0.10 inches versus the control treatment, respectively (Table 5 b and 7).

Photo 1: *Leaning 10-year old longleaf pines one year after the NPK treatment (1500 lbs/ac N-P2O5-K2O = 150 lbs/ac N + P and K). This is an example of too much nitrogen in a young longleaf stand.*

The first four year and second six year height growth increments (13.6 and 15.9 feet) for the control, (12.1 and 16.3 feet) the NPK, and (13.7 and 14.1 feet) the biosolids/pelletized poultry litter (PBL) treatment are presented in Tables 5a, 5b and 7.

Incremental stem wood+bark volume per tree differences between the control, NPK, and biosolids/PBL treatments were negligible in the first four-years after the initial application (1995-99) or the second application period (1999-2005, Table 8). Total volume per acre by fertilizer treatment at study initiation was not significantly different (Table 6a). Total volume per acre increments for the first application period (1995-99) were: control 529 ft3/ac (16.5 tons/ac), NPK 563 ft3/ac (17.6 tons/ac), and biosolids 639 ft3/ac (20 tons/ac, Table 8) with no significant differences among treatments. Total volume per acre increments for the second application period (1999-2005) were: control 1,120 ft3/ac (35 tons/ac), NPK 1,330 ft3/ac (41.6 tons/ac), and pelletized broiler litter 1,123 ft3/ac (35 tons/ac; Table 8) with no significant differences among treatments. Pulpwood (dbh 4 through 6 inches to a 3 inch top) and superpulp (dbh 7 through 9 inches to a 3 inch top) volume increment followed the same trend as total volume with minor gains with NPK and biosolids+ pelletized broiler litter treatments compared to the control, but gains were not significantly different and not economically justifiable (Figure 2a and 2b, Table 8).

Ten-year total volume growth increment was 1,649 ft3/ac (51.5 tons/acre) for the control, 1,893 ft3/ac (59.2 tons/acre) for the NPK two applications, and 1,762 ft3/ac (55 tons/acre) for the biosolids and pelletized broiler litter application. The ten year (age 9 to 19-years) planted longleaf pine stand mean annual increments were 5.2 tons/acre/year for the control, 5.5 tons/acre/year for the lime stabilized biosolids (applied in 1995) then pelletized broiler litter (applied in 1999), and 5.9 tons/acre/year for the two NPK applications.

Longleaf survival over the ten-year study period (age 9- to 19-years old) was greatest (79%) in the control treatment, 75% in the biosolids then pelletized broiler litter plots, and 69% in the NPK two application treatment (Tables 5a and 5b).

**Note photo 1 showing the leaning 10-year-old longleaf pines in the 1,500 lbs/ac 10-10-10 NPK fertilizer treatment. We do not recommend 150 lbs/ac N in these young longleaf stands as a large number of the longleaf trees had excessive lean and never straightened. We recommend that when longleaf stand dbhs are less than 6", apply 75 lbs/ac N with the needed P and K (based on soil and foliar P and foliar K levels). Once longleaf diameters are equal to or greater than 6", then 125-135 lbs/ac N can be applied with needed P and K.

VI. ECONOMICS OF FERTILIZATION

There was a significant pine straw production response to both NPK and the lime stabilized biosolids initial application in the second and third years after application (Figure 1). As this 1986 longleaf pine stand developed without fertilization, pine straw production was essentially the same as the NPK and biosolids treatments by age 13-years (Figure 1, 150 bales/ac). There was a negligible volume production gain with the two NPK applications ($636/ac) and the biosolids+pelletized broiler litter ($596/ac) when compared to the control ($550/ac).

In this case fertilization with two applications of NPK or an application of biosolids then pelletized broiler litter was not financially attractive. The following section will describe why this was the case for this stand on the Alpin soil series.

VII. USE DIAGNOSTIC TOOLS TO MAKE FERTILIZATION PRESCRIPTIONS

The 1986 planted longleaf pine stand had the following diagnostics that indicated that it may not respond significantly to fertilization:

1) Soil available phosphorus (P) averages were above sufficiency (>10 lbs/ac) (Dickens and others 2016) in all three treatment plots in 1995. Soil available phosphorus was 20, 39, and 57 lbs/ac in the control, NPK, and biosolids treatment plots s prior to the first application in 1995 (Table 3).
2) Soil available phosphorus (P) averages were at or above sufficiency in the untreated control plots during the entire 10-year study period (Table 3).
3) Foliar N, P, and K averages were above sufficiency (>0.90% N, 0.08% P, and 0.30% K) in the untreated control plots from the first dormant season collection during 1996, (Table 4) (Dickens and Moorhead 2001).
4) Foliar N, P, and K ten year study period averages (0.94% N, 0.096% P, and 0.33% K) for the untreated control plot longleaf pines were above sufficiency.

Table 1: ***Pre- (1995) and three years post-application (1998) no fertilizer treatment and the fertilization effect using 8 wet tons/ac lime stabilized biosolids and inorganic fertilizer (NPK as 10-10-10; N-P_2O_5-K_2O @ 1,500 lbs/ac) on forest floor mean nutrient concentrations in the 1986 planted longleaf pine stand (Alpin soil) on the Sand Hills State Forest in Chesterfield County, South Carolina.***

		CONCENTRATIONS (%)									
		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
		YEAR									
Treatment	Layer	95	98	95	98	95	98	95	98	95	98
Control	litter	.33	.30	.045	.045	.045	.035	.55	.45	.045	.045
NPK		.33	.29	.035	.035	.055	.06	.62	.43	.055	.045
Biosolids		.33	.35	.035	.035	.035	.03	.37	.52	.035	.045
Control	FH	.95	.37	.04	.04	.025	.04	.30	.48	.02	.035
NPK		.73	.47	.03	.035	.03	.04	.43	.51	.015	.045
Biosolids		.67	.32	.03	.03	.02	.03	.03	.45	.02	.04

Table 2: *Pre- (1995) and three years post-application (1998) no fertilization (control) and the fertilization effect of 8 wet tons/ac lime stabilized biosolids and inorganic fertilizer (NPK as 10-10-10; N-P_2O_5-K_2O @ 1,500 lbs/ac) on forest floor mean estimation of nutrient weights per acre in the 1986 planted longleaf stand (Alpin soil) on the Sand Hills State Forest in Chesterfield County, SC.*

		LBS/ACRE ESTIMATION									
		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
		YEAR									
Treatment	Layer	95	98	95	98	95	98	95	98	95	98
Control	litter	5.6	7.5	.69	1.1	.75	.87	9.2	11	.75	1.1
NPK		6.4	14	.69	1.7	.82	2.9	11	20	1.0	2.2
Biosolids		8.0	17	.73	1.7	.81	1.4	8.5	25	.81	2.2

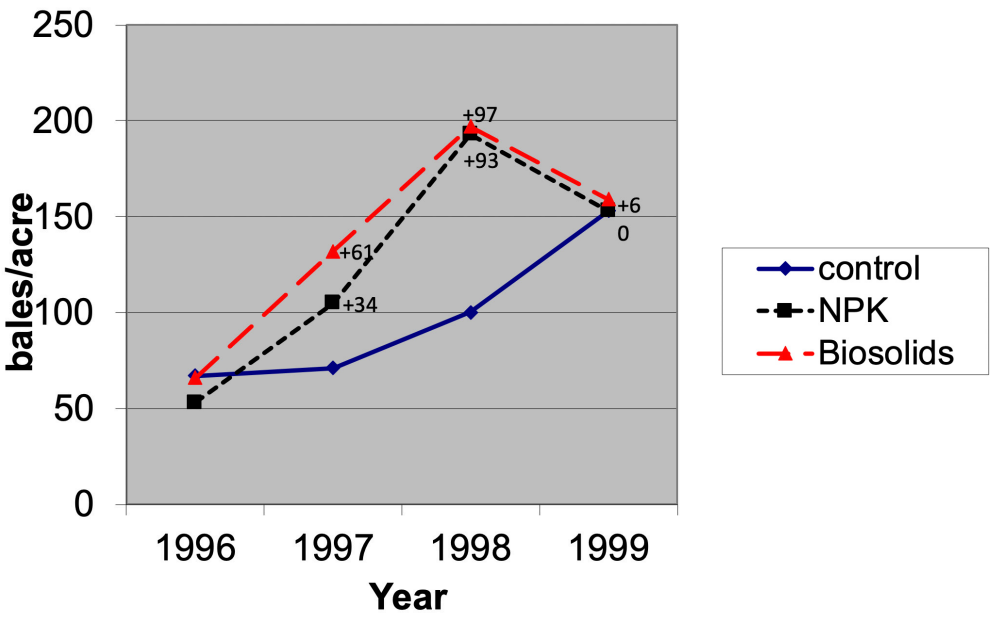

Figure 1: *Pine straw production estimates from February 1996 through February 1999 in the fertilized (@ age 9-yrs) for the 1986 planted longleaf pine stand on an Alpin soil (moderate fertility, deep sand) in Chesterfield, SC. Bale numbers associated with the NPK and biosolids treatments indicate additional bales produced at that stand age as compared to the control. A bale of pine straw (litter layer) was estimated to be 25 lbs.*

Table 3: *Topsoil (0-6") pH, extractable nutrient concentrations, total-N (0-6" and 6-12" pre-, 2-, and 4-year post initial application), and % organic matter (OM) in the 1986 planted longleaf pine stand (Alpin soil) on the Sand Hills State Forest in Chesterfield County, SC*

Fertilizer Treatment	Year	pH	P	K	Ca	Mg	Total-N (0-6")	Total-N (6-12")	% OM
			LB/ACRE				PPM		
Control	1995	4.6	20	20	240	12	971	133	
NPK		4.6	39	12	110	4	206	93	
Biosolids		4.6	57	14	190	8	466	150	
Control	1997	4.6	46	47	230	45	578	202	
NPK		4.4	45	18	180	16	330	150	
Biosolids		5.0	18	18	420	26	430	150	
Control	1999	4.6	12	12	100	12			1.3
NPK		4.6	24	17	80	10			1.3
Biosolids		5.2	18	13	900	19			1.5

1999 WAS 4-YEARS POST INITIAL FERTILIZER APPLICATION AND PRE-2ND APPLICATION

		pH	P	K	Ca	Mg	Cu	B	%OM
Control	2000	4.7	20	13	92	13	0.3	0.1	
NPK		4.6	67	25	207	14	0.3	0.1	
PBL		4.9	19	23	198	18	0.4	0.1	
Control	2002	4.7	26	13	99	12	0.3	0.1	
NPK		4.8	99	25	397	16	0.4	0.1	
PBL		5.5	58	19	607	28	0.6	0.1	
Control	2005	4.6	21	11	122	15	0.4	0.3	1.7
NPK		4.7	54	15	266	17	0.4	0.2	1.5
PBL		5.0	40	16	436	23	0.7	0.3	1.6

Minimum guidelines (sufficiency) longleaf soil test P = 6-10 lbs/acre. Control=no treatment, NPK= 10-10-10 N-P_2O_5-K_2O @ 1500 lbs/ac in 1995 and 850 lbs/ac in 1999, Biosolids = 8 wet tons/ac applied in 1995 only, PBL = Pelletized Broiler Litter applied to biosolids plots in 1999 only.

Table 4: *Foliar nutrient concentrations in a 1986 planted longleaf stand (fertilized first time in May 1995 and second time in May 1999) on the Sand Hills State Forest in Chesterfield County, SC (Alpin soil)*

		LB/ACRE				PPM			
Fertilizer Treatment	**Year**	**N**	**P**	**K**	**Ca**	**Mg**	**B**	**Cu**	**Zn**
		PERCENT					PARTS PER MILLION		
Control	1996	1.04	0.09	0.43	0.16	0.07	10	1.0	40
NPK		**0.89**	*0.08*	0.35	0.15	*0.06*	10	1.0	44
Biosolids		1.21	*0.08*	0.44	0.13	**0.05**	18	1.0	33
Control	1997	**0.85**	0.10	0.38	0.20	*0.06*	10	2.0	38
NPK		**0.89**	0.09	0.57	0.20	**0.05**	12	3.0	40
Biosolids		0.93	0.10	0.33	0.25	0.07	9	2.5	42
Control	1998	**0.78**	0.11	0.30	0.17	0.07		3.0	30
NPK		0.94	0.09	0.56	0.14	0.07		2.5	36
Biosolids		0.99	0.11	0.33	0.24	0.09		3.0	44
Control	1999	**0.89**	*0.08*	**0.28**	0.23	*0.06*		2.5	32
NPK		**0.88**	*0.08*	0.41	0.15	**0.05**		3.0	22
Biosolids		**0.88**	0.10	0.30	0.25	0.07		2.5	37
1999 WAS 4-YEARS POST INITIAL FERTILIZER APPLICATION AND PRE-2ND APPLICATION									
Control	2000	0.93	0.09	**0.29**	0.17	0.08		2.0	34
NPK		1.49	0.11	0.63	0.25	0.07		4.0	44
PBL		1.13	0.10	0.57	0.26	0.07		3.5	43
Control	2001	0.91	0.10	**0.26**	0.27	*0.06*		2.0	31
NPK		1.13	0.10	0.57	0.21	*0.06*		2.5	43
PBL		1.01	0.09	0.39	0.22	0.08		2.5	33
Control	2002	0.94	0.10	0.39	0.20	0.08		3.0	29
NPK		1.02	0.11	0.51	0.16	**0.04**		2.5	30
PBL		0.96	0.10	0.47	0.26	0.07		3.0	32
Control	2003	0.97	0.10	0.33	0.18	0.09	12	2.5	34
NPK		1.02	0.11	0.45	0.20	0.07	11	3.0	34
PBL		1.01	0.10	0.43	0.20	0.08	12	3.0	33

Minimum guidelines longleaf foliage nutrient concentrations are: 0.90% N, 0.08% P, 0.30% K 0.10% Ca, and 0.06% Mg (Blevins and others 1996, Dickens and Moorhead 2001). ***Bold*** *nutrient values are below sufficiency and italicized nutrient values are at sufficiency. Control=no treatment, NPK= 10-10-10 N-P_2O_5-K_2O @ 1500 lbs/ac in 1995 and 850 lbs/ac in 1999, Biosolids = 8 wet tons/ac applied in 1995, PBL = Pelletized Broiler Litter applied to biosolids plots in 1999*

Table 5a: *Mean trees per acre, dbh, height, and volume/tree by treatment from 1995 through 1999 for the 1986 planted longleaf stand (fertilized in May 1995 and May 1999) on the Sand Hills State Forest in Chesterfield County, SC (Alpin soil).*

YEAR	TREATMENT	TREES/ ACRE	DBH (IN)	TOTAL HEIGHT (FT)	VOLUME/TREE (FT3)
1995	control	476	3.1	17.1	0.48
	NPK	556	2.8	16.6	0.37
	Biosolids	526	3.0	16.9	0.45
1997	control	440	3.9	23.5	1.0
	NPK	518	4.0	21.4	1.0
	Biosolids	484	4.0	22.7	1.0
1999	control	436	4.5	30.7	1.7
	NPK	462	4.6	28.1	1.7
	Biosolids	444	4.6	30.6	1.8

There were no statistically significant differences among treatment means within a measurement year for the parameters listed above using Duncan's Multiple Range Procedure at the 5% alpha level. Control=no treatment, NPK=1,500 lbs/ac 10-10-10 N-P_2O_5-K_2O, Biosolids= lime stabilized biosolids (8 wet tons/ac)

Table 5b: *Mean trees per acre, dbh, height, and volume/tree by treatment from 1999 through 2005 for the 1986 planted longleaf stand (fertilized in May 1995 and May 1999) on the Sand Hills State Forest in Chesterfield County, SC (Alpin soil).*

YEAR	TREATMENT	TREES/ ACRE	DBH (IN)	TOTAL HEIGHT (FT)	VOLUME/TREE (FT3)
1999	control	436	4.5	30.7	1.7
	NPK	462	4.6	28.1	1.7
	PBL	444	4.6	30.6	1.8
2002	control	384	5.5	37.3	3.1
	NPK	384	6.0	35.8	3.5
	PBL	396	5.6	37.2	3.2
2005	control	378	6.3	46.6	5.0
	NPK	382	6.8	44.4	5.5
	PBL	394	6.5	44.7	5.1

There were no statistically significant differences among treatment means within a measurement year for the parameters listed above using Duncan's Multiple Range Procedure at the 5% alpha level. Control=no treatment, NPK= 10-10-10 N-P_2O_5-K_2O @ 1,500 lbs/ac in 1995 and 850 lbs/ac in 1999, Biosolids = 8 wet tons/ac applied in 1995, PBL = Pelletized Broiler Litter applied to biosolids plots in 1999

Table 6a: *Mean total stem wood+bark volume per acre, pulpwood (PW; 4-6" dbh, 3" top), superpulp (SP; 7-9" dbh, 3" top), and total pulpwood (TPW; includes PW and SP) volume per acre by treatment from 1995 through 1999 for the 1986 planted longleaf pine stand on the Sand Hills State Forest, SC.*

YEAR	TREATMENT	TOTAL VOLUME/AC (FT3)	PW VOLUME/AC (FT3)	SP VOLUME/AC (FT3)	TPW VOLUME/AC (FT3)
1995	control	231	3	--	3
	NPK	208	10	--	10
	Biosolids	238	11	--	11
1997	control	446	137	--	137
	NPK	504	181	6	187
	Biosolids	505	153	17	170
1999	control	760	436	--	436
	NPK	771	432	130	562
	Biosolids	877	483	69	552

There were no statistically significant differences among treatment means within a measurement year for the parameters listed above using Duncan's Multiple Range Procedure at the 5% alpha level. Control=no treatment, NPK=1,500 lbs/ac 10-10-10 N-P_2O_5-K_2O, Biosolids= 8 wet tons/ac lime stabilized biosolids. Divide ft3/ac by 32 to estimate tons/ac.

Table 6b: *Mean total volume per acre, pulpwood (PW; 4-6" dbh, 3" top), superpulp (SP; 7-9" dbh, 3" top), and total pulpwood (TPW; includes PW and SP) volume per acre by treatment from 1999 through 2005 for the 1986 planted longleaf pine stand on the Sand Hills State Forest, SC.*

YEAR	TREATMENT	TOTAL VOLUME/AC (FT3)	PW VOLUME/AC (FT3)	SP VOLUME/AC (FT3)	TPW VOLUME/AC (FT3)
1999	control	760	436	--	436
	NPK	771	432	130	562
	PBL	877	483	69	552
2002	control	1,187	524	380	904
	NPK	1,350	436	656	1,091
	PBL	1,264	589	417	1,006
2005	control	1,880	460	1,193	1,653
	NPK	2,101	386	1,462	1,848
	PBL	2,000	403	1,347	1,750

There were no statistically significant differences among treatment means within a measurement year for the parameters listed above using Duncan's Multiple Range Procedure at the 5% alpha level. Control=no treatment, NPK= 10-10-10 N-P_2O_5-K_2O @ 1,500 lbs/ac in 1995 and 850 lbs/ac in 1999, biosolids = 8 wet tons/ac applied in 1995, PBL = Pelletized Broiler Litter applied to biosolids plots in 1999. Divide ft3/ac by 32 to estimate tons/ac.

Table 7: *Growth increment between measurement periods for dbh, total height, and volume/tree by treatment from 1995-1999 and 1999-2005 for the 1986 planted longleaf pine stand on the Sand Hills State Forest, SC (Alpin soil series).*

PERIOD	TREATMENT	DBH (IN)	TOTAL HEIGHT (FT)	VOLUME/TREE (FT3)
1995-1999	control	1.4	13.6	1.22
	NPK	1.8	11.5	1.33
	Biosolids	1.6	13.7	1.35
1999-2005	control	1.8	15.9	3.3
	NPK	2.2	16.3	3.8
	PBL	1.9	14.1	3.3

There were no statistically significant differences between treatment means within a measurement year for the parameters listed above using Duncan's Multiple Range Procedure at the 5% alpha level. Control=no treatment, NPK=10-10-10 N-P_2O_5-K_2O @1500 lbs/ac in 1995 and 850 lbs/ac in 1999, Biosolids = 8 wet tons/ac applied in 1995, PBL = Pelletized Broiler Litter applied in biosolids plots in 1999 with no second dose of biosolids in the biosolids plots)

Table 8: *Growth increment between measurement periods for total stem wood+bark volume per acre, pulpwood (PW; 4-6" dbh, 3" top), superpulp (SP; 7-9" dbh, 3" top), and total pulpwood (TPW = PW + SP) volume per acre by treatment from 1995-1999 and 1999-2005 for the 1986 planted longleaf pine stand on the Sand Hills State Forest, SC (Alpin soil series).*

PERIOD	TREATMENT	TOTAL VOL/AC (FT3)	PW VOL/AC (FT3)	SP VOL/AC (FT3)	TPW VOL/AC (FT3)
1995-1999	control	529	433	0	433
	NPK	563	422	130	552
	Biosolids	639	472	69	541
1999-2005	control	1,120	25	1,193	1,218
	NPK	1,330	- 74	1,313	1,239
	PBL	1,123	- 14	1,313	1,299

There were no statistically significant differences among treatment means within a measurement year for the parameters listed above using Duncan's Multiple Range Procedure at the 5% alpha level. Control=no treatment, NPK=10-10-10 N-P_2O_5-K_2O @ 1,500 lbs/ac in 1995 and 850 lbs/ac in 1999, Biosolids = 8 wet tons/ac applied in 1995, PBL = Pelletized Broiler Litter applied in biosolids plots in 1999 with no second dose of biosolids in the biosolids plots). Divide ft3/ac by 32 to estimate tons/ac.

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